3.1 THE NATIONAL POLAR-ORBITING OPERATIONAL ENVIRONMENTAL SATELLITE SYSTEM FUTURE U.S. ENVIRONMENTAL OBSERVING SYSTEM

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1. INTRODUCTION

Over the last seven years, a tri-agency Integrated Program Office (IPO), comprised of the Department of Commerce's (DOC) National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DoD), and the National Aeronautics and Space Administration (NASA) has been managing the development of the National Polar-orbiting Operational Environmental Satellite System (NPOESS). The NPOESS program represents a major step toward the merger of U.S. civilian and military operational meteorological satellites into a single, integrated, end-to-end satellite system. Once operational later this decade, NPOESS will replace the current NOAA Polar-orbiting Operational Environmental Satellites (POES) and the Defense Meteorological Satellite Program (DMSP) systems, each with over a 40-year heritage of successful service. The POES and DMSP spacecraft have revolutionized the way in which we observe and predict the weather. With the development of NPOESS, we will evolve and expand our capabilities to observe, assess, and predict the total Earth system - atmosphere, ocean, land, and the space environment.

The IPO, which is located organizationally within NOAA, is responsible for developing, managing, acquiring, and operating NPOESS. The Integrated Program Office concept provides each of the participating agencies with lead responsibility for one of three primary functional areas. NOAA has overall responsibility for the converged system and is also responsible for satellite operations. NOAA is also the primary interface with the international and civil user communities. DoD is responsible to support the IPO for major systems acquisitions, including launch support. NASA has a primary responsibility for facilitating the development and incorporation of new cost-effective technologies into the converged system. Although each agency provides certain key personnel in their lead role, tri-agency work teams staff each functional division to maintain the integrated approach.

Significant progress has been made in bringing the concept of a converged polar-orbiting environmental satellite system into an operational reality. The focus has always been on the larger issues affecting NPOESS. These include: 1) a program that will save $1.8 billion over the life cycle of the system, 2) a program content that will satisfy both civil and national security needs, 3) equal cost sharing by NOAA and the Department of Defense, and 4) infusion of new technologies from NASA to meet both operational and selected research mission requirements. Interagency efforts with NPOESS will result in continuing and improving the critical satellite measurements necessary to provide timely and accurate forecasts and warnings to the public and to conduct worldwide military operations. NPOESS will also deliver environmental data and information to support the U.S. economy and provide continuity of critical data for monitoring, understanding, and predicting climate change and assessing the impacts of climate change on seasonal and longer time scales.

2. REQUIREMENTS

The NPOESS development and acquisition plan is designed to make best use of production and existing POES and DMSP assets, to reduce risk on critical sensor payloads and algorithms, and to leverage civil, governmental, and international payload and spacecraft developments. The planned evolution from the current POES and DMSP programs to NPOESS is depicted in Figure 1. The current detailed timeline for the transition is shown in Figure 2. Currently the U.S. is operating two POES and two DMSP primary satellites. With the launch in 2005 of the first polar-orbiting Metop satellite by the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), there will be one POES, one Metop, and two DMSP satellites in four orbital planes. The first converged NPOESS satellite must be available for launch by 2008 to back-up the last launches of the current DMSP and POES satellites. The first launch of NPOESS is planned for 2009.

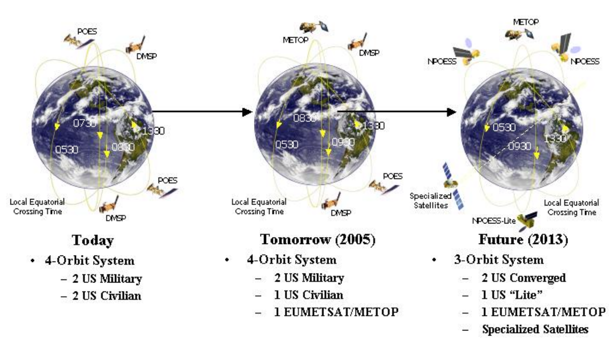

Figure 1. The NPOESS Evolution – 2001 to 2013

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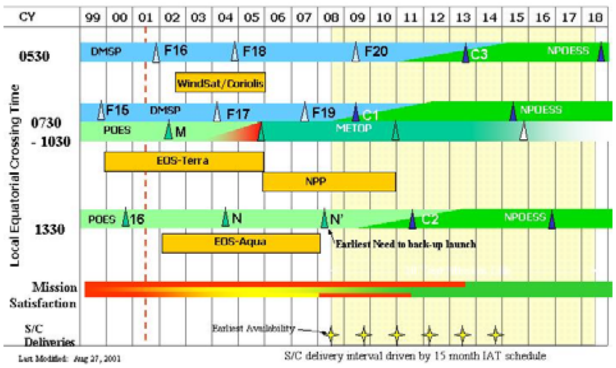

Figure 2. The NPOESS Schedule

The agencies participating in the NPOESS development have agreed upon a fully defined set of integrated operational requirements that will meet the needs of the nation's civil and military users for satellite data. The established requirements for 55 atmospheric, oceanic, terrestrial, and solar-geophysical data products are guiding the development of advanced technology visible, infrared, and microwave imagers and sounders that will provide enhanced capabilities to users and improve the accuracy and timeliness of observations. The 55 NPOESS Environmental Data Records (Figure 3) fully encompass the Earth science disciplines. When operational, NPOESS will truly be an "environmental observing system," not just an advanced "weather" satellite.

Figure 3. NPOESS Environmental Data Records

3. INSTRUMENTS AND SYSTEMS DEVELOPMENT

In 1997, the IPO initiated a robust sensor risk reduction effort that has been focused on early development of the critical sensor suites and algorithms necessary to support NPOESS. In August 2001, preliminary design efforts were completed for the last of five critical imaging/sounding instruments for NPOESS. Final design, prototype development, and fabrication of these instruments have begun, with delivery of the first flight units for three sensors scheduled for late 2004. In 2000, the IPO initiated a program definition and risk reduction program to define the requirements for the NPOESS total system architecture, including space, ground processing, and command, control, and communications components, as well as to develop specifications for sensor/spacecraft integration. This phase of the early development program will be concluded in late 2002, with the award of a single contract for the Engineering and Manufacturing Development of NPOESS.

To support the converged civil and military requirements for space-based, remotely sensed environmental data, the NPOESS spacecraft will carry the following payloads (Figure 4):

NPOESS Instruments	0530	NPOESS Lite 0930	1330	METOP 0930	NPP 1030	TBD
IPO Developed						
Visible/IR Imager Radiometer Suite (VIIRS)*	X	X	X		X	
Cross-track IR Sounder (CrIS)*			X	X (IASI/HIRS)	X	
Conical MW Imager/Sounder (CMIS)*	X	X	X			
Ozone Mapper/Profiler Suite (OMPS)			X	X (GOME)		X
GPS Occultation Sensor (GPSOS)	X		X	X (GRAS)		
Space Environmental Sensor Suite (SESS)	X		X	X (SEM)		
Polarimeter (new)		X				
Leveraged						
Advanced Technology MW Sounder (ATMS)*			X	X (AMSU/MHS)	X	
Data Collection System (DCS)	X		X	X		
Search and Rescue (SARSAT)	X		X	X		
Earth Radiation Budget Sensor			X			
Solar Irradiance Sensor (TSIS)	X					
Radar altimeter (ALT)						X[1]
Advanced Scatterometer (ASCAT)				X		

* Critical instrument - Failure constitutes need to replace satellite [1] Altimeter options: NPOESS-lite or free flyer

Figure 4. The NPOESS Sensors

- Visible/Infrared Imager Radiometer Suite (VIIRS): The VIIRS will combine the radiometric accuracy of the AVHRR currently flown on the NOAA polar orbiters with the high (0.65 kilometer) spatial resolution of the Operational Linescan System flown on DMSP spacecraft. The VIIRS will have 22 channels with additional spectral capabilities that can be utilized to determine ocean color. VIIRS will provide measurements of sea surface temperature, atmospheric aerosols, snow cover, cloud cover, surface albedo, vegetation index, sea ice, and ocean color.
- Cross-track Infrared Sounder (CRIS): The CrIS is a Michelson Interferometer that is designed to enable retrievals of atmospheric temperature profiles at 1 degree accuracy for 1 km layers in the troposphere, and moisture profiles accurate to 15 percent for 2 km layers.
- Conical-scanning Microwave Imager Sounder (CMIS): The CMIS will combine the microwave imaging capabilities of Japan's Advanced Microwave Scanning Radiometer (AMSR) on NASA's Earth Observing System (EOS) Aqua mission, and the atmospheric sounding capabilities of the Special Sensor Microwave Imager/ Sounder (SSMI/S) on the remaining series of DMSP satellites that will begin launching in November 2001. Polarization for selected imaging channels will be utilized to derive ocean surface wind vectors similar to what has previously been achieved with active scatterometers. CMIS data will be utilized to derive a variety of parameters, including all weather sea surface temperature, surface wetness, precipitation, cloud liquid water, cloud base height, snow water equivalent, surface winds, atmospheric vertical moisture profile, and atmospheric vertical temperature profile.

- Ozone Mapping and Profiler Suite (OMPS): The OMPS will consist of a nadir scanning ozone mapper similar in functionality to NASA's Total Ozone Mapping Spectrometer (TOMS) and a limb scanning radiometer that will be able to provide ozone profiles with a vertical resolution of 3 km as compared to the present 7 to 10 km for the SBUV on POES.
- Global Positioning System Occultation Sensor (GPSOS): The GPSOS will be used operationally to characterize the ionosphere and to determine tropospheric temperature and humidity profiles.
- Space Environment Sensor Suite (SESS): The SESS will provide information about the space environment necessary to ensure reliable operations of current space-based and ground-based systems, to facilitate the analysis of system anomalies that are the result of space environmental effects, and to guide the design and efficient operations of future systems that may be affected by the space environment.
- Aerosol Polarimeter: The aerosol polarimeter will measure along-track scene intensity as a function of wavelength and polarization to determine aerosol optical thickness, aerosol particle size, cloud particle size distribution, aerosol refractive index, and single scattering albedo and shape. The polarimeter will work in conjunction with and complement the VIIRS measurements.
- Advanced Technology Microwave Sounder (ATMS): The ATMS is being designed to be the next generation cross-track microwave sounder and will combine the capabilities of microwave temperature sounders (AMSU-A) and microwave humidity sounders (MHS/HSB) that fly on NOAA's POES, EUMETSAT's Metop, and NASA's EOS Aqua spacecraft.
- Cloud and Earth's Radiant Energy System (CERES): CERES will provide data on the Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface. The first CERES is currently flying on NASA's Tropical Rainfall Measuring Mission (TRMM) that was launched in November 1997. The IPO will procure the latest version of CERES as a leveraged payload for flight on the NPOESS spacecraft.
- Total Solar Irradiance Sensor (TSIM): The TSIM will measure variability in the sun's solar output, including total solar irradiance in the 200 to 300nm and 1500 nm spectral ranges. The IPO currently plans to fly copies of the Total Irradiance Monitor (TIM) and Solar Irradiance Monitor (SIM), being developed for NASA by the University of Colorado=s Laboratory for Atmospheric and Space Physics (LASP). The two instruments together, termed TSIM, will be acquired as a leveraged payload for flight on the NPOESS spacecraft.
- Radar Altimeter (ALT): The IPO is planning to fly a dual frequency radar altimeter on the morning NPOESS satellite. The altimeter will measure sea surface topography, significant wave height, and wind speed, and altimetry measurements will be used to derive ocean circulation parameters monitoring requirements for both operations and research purposes. The altimeter will be acquired as a leveraged payload for flight on the NPOESS spacecraft.
- Search and Rescue Satellite Aided Tracking System (SARSAT): The SARSAT receives distress signals from emergency beacons on international distress frequencies and retransmits them to local user terminals for action by appropriate government agencies.
- ARGOS/Data Collection System (DCS): The DCS relays meteorological and other data transmitted from *in-situ* ground-based data collection platforms including buoys, free floating balloons, and remote weather stations.

4. EARLY FLIGHT TESTING

As a critical part of the NPOESS development strategy, early flight-testing of instruments is planned to reduce development risk and to demonstrate and validate global imaging and sounding instruments, algorithms, and pre-operational ground systems prior to the first NPOESS flight in 2008. The joint DoD/IPO WindSat/Coriolis mission will be launched in 2002 to provide a space-based test and demonstration of passive microwave polarimetric techniques to derive measurements of ocean surface wind speed and direction. This three-year mission will continue the development of improved microwave measurement capabilities from the Special Sensor Microwave Imager and Sounder (SSMI/S) on DMSP to CMIS on NPOESS.

The NPOESS Preparatory Project (NPP), a joint IPO/NASA mission that is being planned for launch in late 2005, will carry three of the critical NPOESS sensors (VIIRS, CrIS, and ATMS) to provide on-orbit testing and validation of sensors, algorithms, and ground-based operations and data processing systems while the current operational POES and DMSP and the NASA Earth Observing System (EOS) research satellite systems (Terra and Aqua) are still in place. The NPP mission will provide operational agencies early access to the next generation of operational sensors, thereby greatly reducing the risks incurred during the transition from POES and DMSP to NPOESS. NPP will demonstrate the utility of the improved imaging and radiometric data in short-term weather "nowcasting" and forecasting and in other oceanic and terrestrial applications, such as harmful algal blooms, volcanic ash, and wildfire detection.

In addition to serving as a valuable risk reduction and prototyping mission for the IPO and users of NPOESS data, NPP will provide continuity of the calibrated, validated, and geo-located NASA EOS Terra and Aqua missions systematic global imaging and sounding observations for NASA Earth Science research. With a five-year design lifetime, NPP will provide data past the planned lifetime of EOS Terra and Aqua and provide a "bridge" to the operational NPOESS mission. NPP will extend the series of key measurements in support of long-term monitoring of climate change and of global biological productivity.

5. OPERATIONS

The current operational concept for NPOESS consists of a constellation of spacecraft flying at an altitude of 833 km in three sun-synchronous (98.7 degree inclination) orbital planes with equatorial nodal crossing times of 0530, 0930, and 1330 local solar time (LST), respectively. NPOESS is being designed for precise orbit control to maintain altitude, nodal crossing times to within ± 10 minutes throughout the mission lifetime, and repeat ground tracks for certain measurements. The early morning (0530) and afternoon (1330) spacecraft will carry full complements of instruments. The mid-morning (0930) NPOESS-"Lite" spacecraft will carry a reduced complement of instruments, including VIIRS and CMIS that are required to meet the stringent U.S. horizontal resolution and data refresh requirements for all-weather imaging in this orbit. The IPO plans to continue cooperation with EUMETSAT for a Joint Polar System (JPS). While in a transition phase to a future international polar satellite program, the NPOESS-"Lite" spacecraft will complement EUMETSAT's third Metop satellite flying in the 0930 orbit. Use of data from EUMETSAT's Metop satellite will increase the global coverage and refresh rate of the U.S. polar satellite system. In addition, the European meteorological community will receive valuable data from instruments on both the Metop and NPOESS series of satellites.

6. DATA AVAILABILITY

To meet U.S. requirements for the 55 geophysical parameters, the NPOESS Command, Control, and Communications (C3) system will deliver global Stored Mission Data to four (4) U.S. Operational Processing Centers (Centrals) for processing and distribution. These Centrals are: the National Environmental Satellite, Data, and Information Service (NESDIS)/National Centers for Environmental Prediction (NCEP), the Air Force Weather Agency (AFWA), Fleet Numerical Meteorology and Oceanography Center (FNMOC), and the Naval Oceanographic Office (NAVOCEANO). Global Stored Mission Data (SMD) will be the complete, full resolution data set containing all sensor data and auxiliary data necessary to generate all NPOESS Environmental Data Records (EDR) at the Centrals. The IPO will install an Interface Data Processor Segment (IDPS) at each of the four (4) Centrals to process NPOESS Raw Data Records (RDR) into EDRs. Processing RDRs into Environmental Data Records (EDRs) will require production of intermediate-level satellite instrument Sensor Data Records (SDRs). This intermediate-level data will be available through the Centrals as retrievable data records.

Three types of NPOESS data will be made available through the four (4) U.S. Centrals:

- Raw Data Records will be full resolution, unprocessed digital sensor data, time-referenced and earth (GEO) located (or orbit-located for *in-situ* measurements), with radiometric and geometric calibration coefficients appended, but not applied, to the data. Aggregates (sums or weighted averages) of detector samples are considered to be full resolution data if the aggregation is normally performed to meet resolution and other requirements. Sensor data will be unprocessed with the following exceptions: time delay and integration (TDI), detector array non-uniformity correction (i.e., offset and responsivity equalization), and lossless data compression are allowed. All calibration data will be retained and communicated to the ground without lossy compression. For the real-time transmission of raw data to field terminals, lossy compression will be allowed. Additionally, reduced resolution will be allowed in transmission of raw data to LRD field terminals.
- Sensor Data Records will be full resolution sensor data that are time referenced, earth (GEO) located (or orbit-located for *in-situ* measurements), and calibrated by applying the ancillary information, including radiometric and geometric calibration coefficients and geo-referencing parameters, such as platform ephemeris. These data are processed to sensor units (e.g., radar backscatter cross section, brightness temperature, radiance, etc.). Calibration, ephemeris, and any other ancillary data necessary to convert the sensor units back to sensor raw data (counts) are included.
- Environmental Data Records will be fully processed sensor data that contain the environmental (geophysical) parameters or imagery that must be generated as user products, as well as any ancillary data required to identify or interpret these parameters or images. EDRs will be generated by the NPOESS IPDS at each of the Centrals (or by IDPS software running on NPOESS compatible HRD or LRD field terminals) by applying appropriate algorithms to RDRs/SDRs.

At each of the four (4) Centrals, the NPOESS IDPS will store the raw data, process these data into SDRs and EDRs, using auxiliary and ancillary data as necessary, and store these processed data. The IDPS will provide sufficient temporary storage capacity (i.e., storage capacity for multiple passes – minimum of 24 hour storage) to store the RDRs/SDRs/EDRs and ancillary data for immediate use in the Centrals' higher-level product applications. Longer-term storage and archive of RDRs/SDRs/EDRs for use by the Centrals will be the responsibility of the respective Central. NOAA will maintain the long-term archive of NPOESS data. Centrals may provide the raw and processed NPOESS data to local systems and other users, as required. The four (4) Centrals will be responsible for distributing NPOESS data and higher-level products to their respective users. NOAA will be responsible for providing the worldwide user community access to near real-time processed NPOESS data and higher-level products, as well as access to archived NPOESS data. Other non-government users may also have an independent capability to receive NPOESS data. The processing, archiving, and dissemination of these data by independent users will be their responsibility.

NPOESS spacecraft will also simultaneously broadcast two types of real-time data to suitably equipped ground stations. These direct broadcast/real-time ground stations (or field terminals) will be capable of processing NPOESS RDRs into EDRs by utilizing IDPS software appropriate for the type of field terminal. The NPOESS

High Rate Data (HRD) broadcast will be a complete, full resolution data set containing all sensor data and auxiliary data necessary to generate all NPOESS EDRs and is intended to support users at regional hubs. The HRD broadcast will be transmitted at X-band frequencies, at a data rate of about 20 Mbps, and will require a bandwidth of nearly 50 MHz, with a receive antenna aperture not to exceed 2.0 meters in diameter. The NPOESS Low Rate Data (LRD) broadcast will be a subset of the full data set and is intended for U.S. and worldwide users of field terminals (land and ship-based, fixed and mobile environmental data receivers operated by DoD users and surface receivers operated by other U.S. government agencies, worldwide weather services, and other international users). Some data compression (Lossy or Lossless) may be employed for the LRD link. The LRD L-band broadcast will provide data at a rate of 3.5 Mbps at 1702.5 MHz with a receive antenna aperture not to exceed 1.0 meter diameter. The NPOESS LRD broadcast parameters (frequency, bandwidth, data rate, and data content) were selected to satisfy U.S. requirements for low-rate, real-time direct broadcast, as well as to be closely compatible with the broadcast parameters for the Advanced High Resolution Picture Transmission (AHRPT) format that will be used on the EUMETSAT Metop spacecraft. The NPOESS LRD broadcast is expected to provide microwave (from CMIS) and infrared (CrIS) sounding data, and selected imagery channels (from VIIRS). Future communications capabilities may allow other-than-direct data transmission to follow-on field terminal systems.

7. SUMMARY

The development of NPOESS represents a significant and exciting change in the way the United States acquires, manages, and operates environmental satellites. The advanced technology visible, infrared, and microwave imagers and sounders that are being developed for NPOESS will deliver higher spatial and temporal resolution atmospheric, oceanic, terrestrial, and solar-geophysical data enabling more accurate short-term weather forecasts and severe storm warnings, as well as serving the data continuity requirements for improved global climate change assessment and prediction. The improved accuracy in atmospheric temperature and humidity soundings from these instruments, in combination with other observations expected to become available over the next ten years, will enable the current 3- to 5-day short-term weather forecasts to be improved from 70 to 80 percent to better than 90 percent and to be extended to 5 to 7 days with 80-percent accuracy. The agencies and industrial partners who are designing and building NPOESS are well on their way to creating a system that will cost less, be more responsive to user demands, and provide sustained, space-based measurements as a cornerstone of an Integrated Global Observing System. The U.S. and international communities will continue to benefit from this new way of doing business well into the 21st century.